



National Aeronautics and
Space Administration

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Pasadena, California



Surface Water and Ocean Topography (SWOT) Mission

Science Team

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LR L2 product: description and open points

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Reviewed and determined not to contain export controlled material.

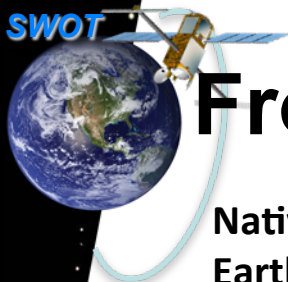


LR L2 Product

- Introduction
- KaRIn Beam geometry, accuracy and combination algorithm
- Product description
 - Overview of Level-2 LR product
 - Gridding
 - Product content
- Remaining work - Discussion



From 9 beam interferograms to 1km² SSH product



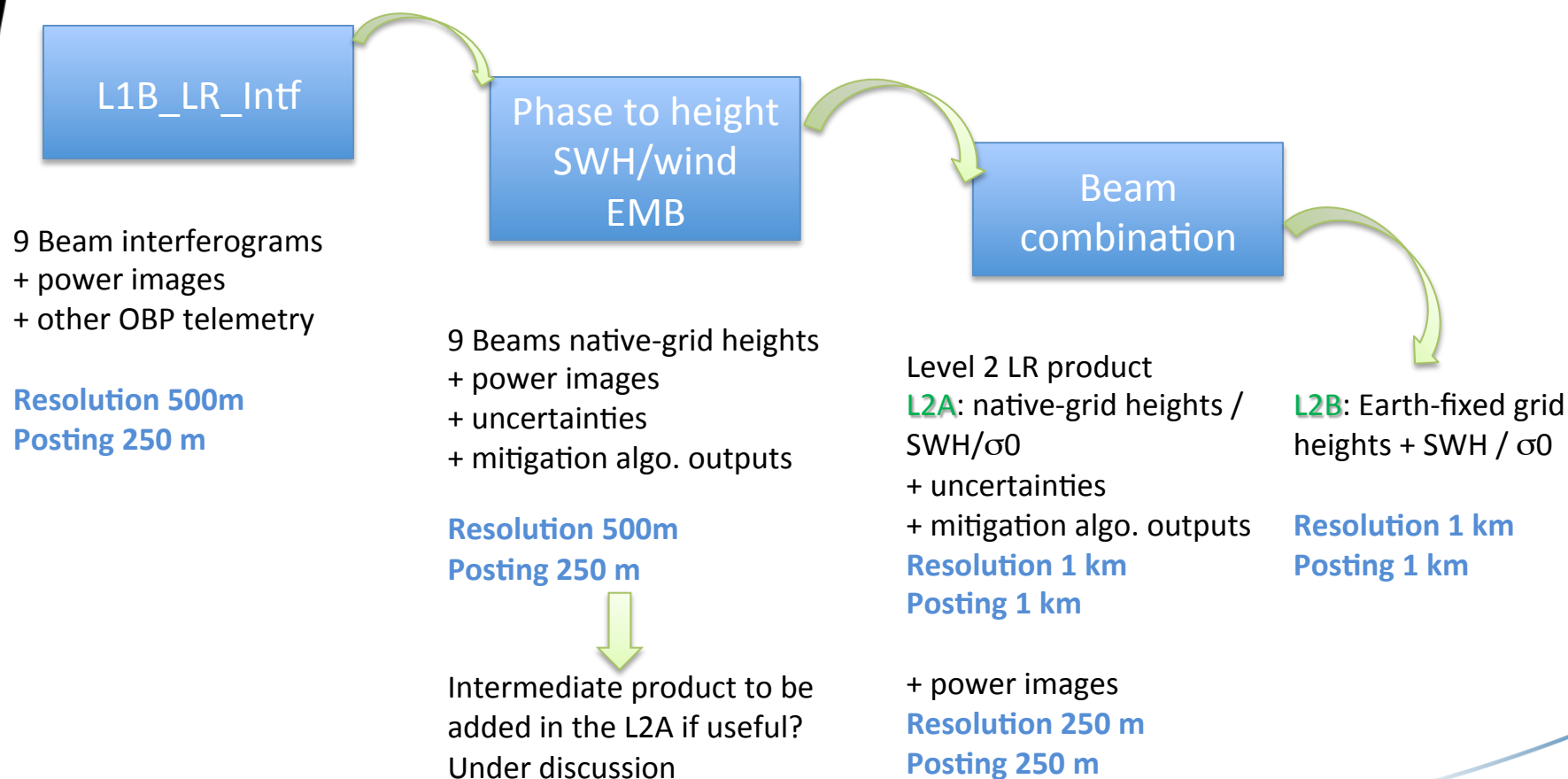
From L1B_LR_Intf to L2A_LR/L2B_LR

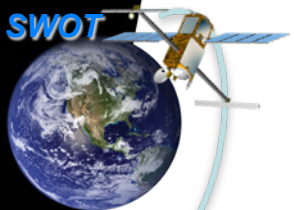
Native-grid = the closest as possible to the measurement geometry, ~ Central beam geometry

Earth-fixed grid = baseline is a grid based on the nominal SWOT tracks (so with the +/- 1km across track variation within it)

Resolution = equivalent surface over which the elementary data have been averaged

Posting = spatial sampling interval

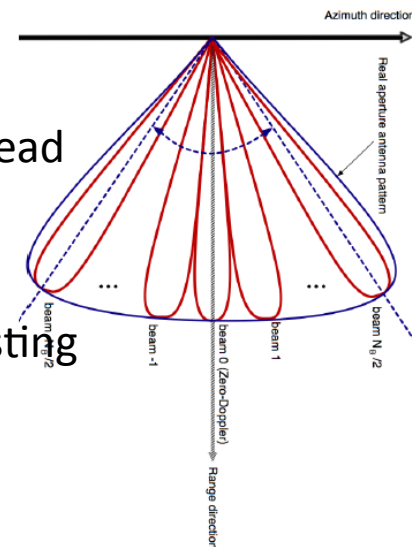




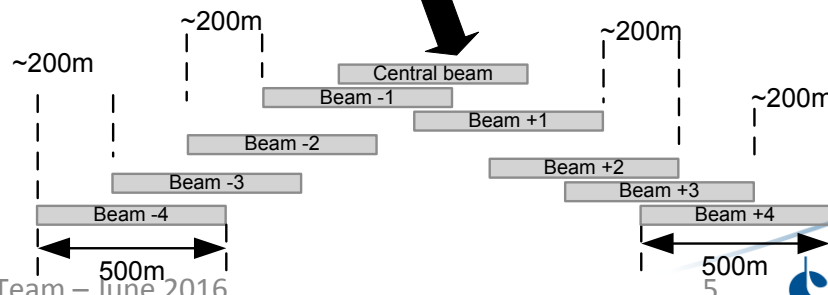
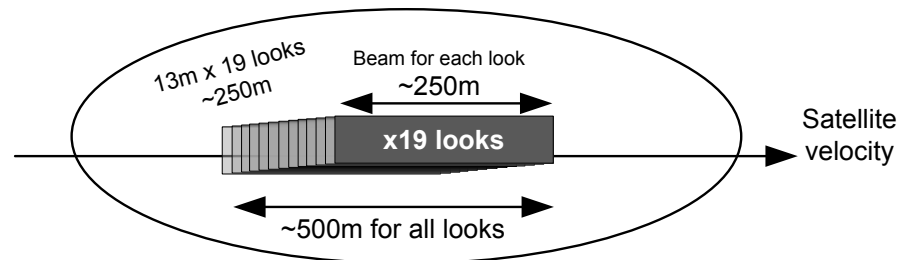
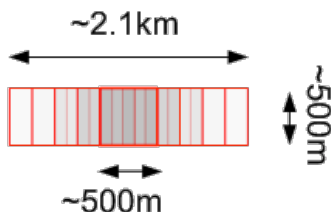
KaRIN's geometry

Origin and geometry of the beams :

- KaRIN measurement is made of 9 squint angles or beams, spread out in the azimuth (along-track) direction
- Each measurement time yields one line in 9 separate images
- Each image is made of 500 m x 500 m pixels with a 250 m posting in along and across-track directions (on-board averaging)
- The 9 images (or beams) are shifted by approximately 200 m each
- The center beams are more reliable than the outer beams

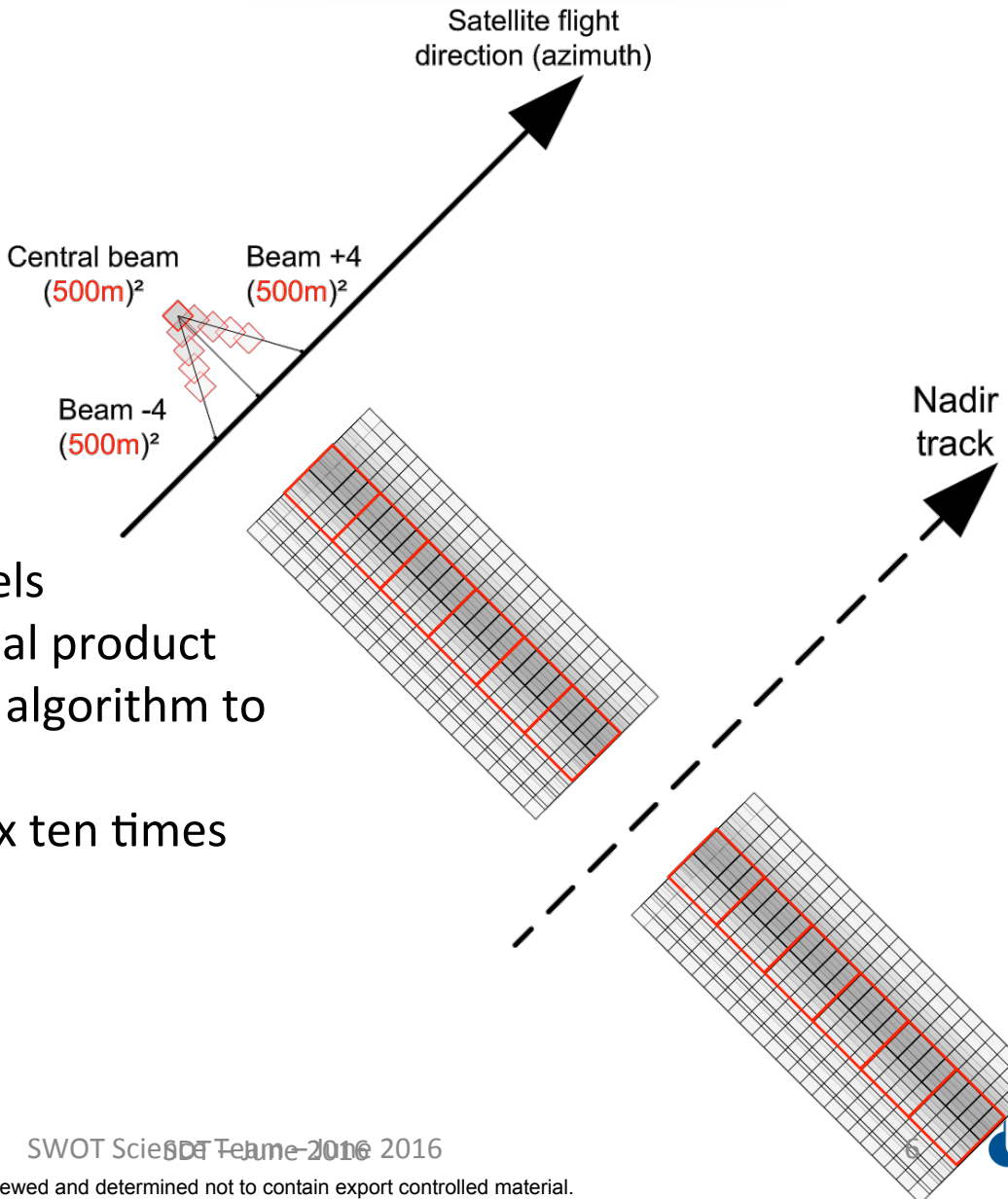


200m translation between 500m pixels x 9 beams





Beams geometry



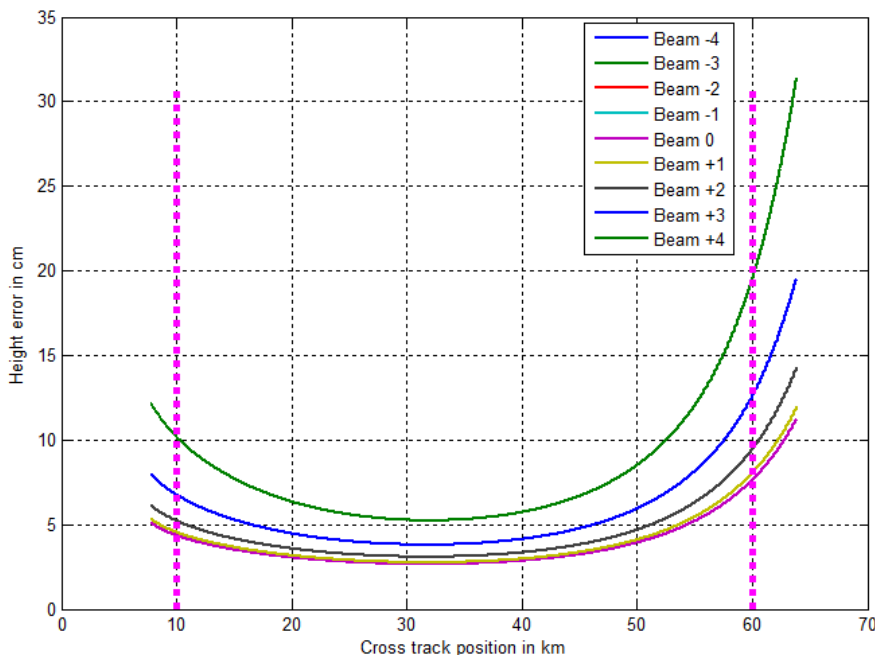
- ✓ Massive overlap of OBP pixels in each $1km^2$ pixel of the final product
- ✓ Used by beam combination algorithm to reduce noise
- ✓ KaRIN directionality: approx ten times more overlap in azimuth



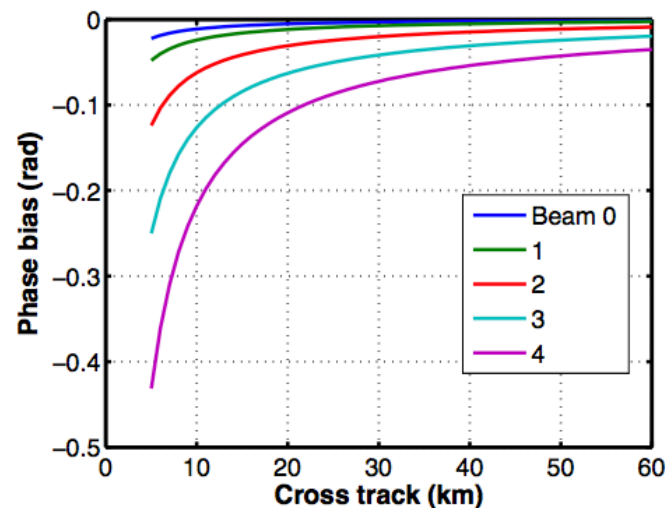
Beam accuracy

Each beam uses a different part of the azimuth antenna pattern with a different gain
 => Each beam measurement has a different noise related to its SNR

500m/250m – random error in the swath for each beam
 With PDR SNR margin

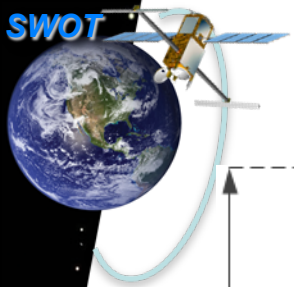


The measured phase contains a term dependent on the azimuth look angle, which introduces a systematic height bias term associated with the instantaneous azimuth look angle

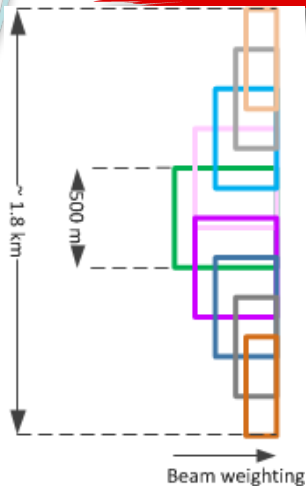


Beam combination algorithm aims to use these high-resolution data optimally

In case of specific data editing, outlier detection needed => these highest resolution data represent a useful tool to build an optimal combined product



Beam combination algorithm

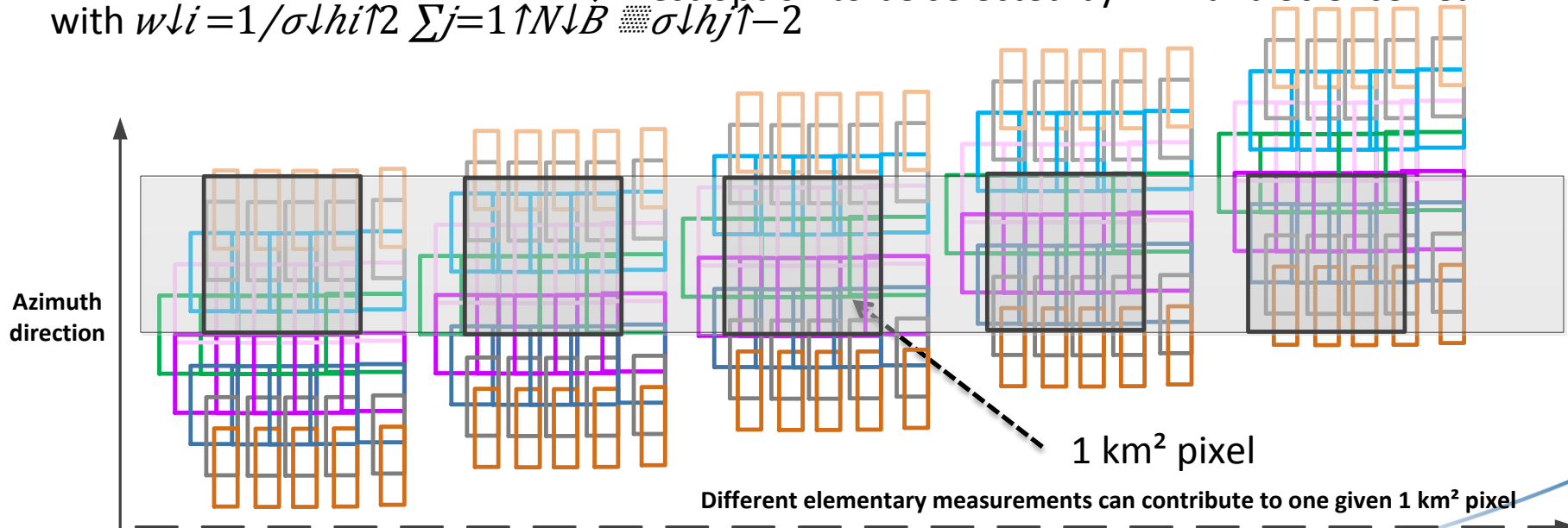


- **Beam weight:** use the error bar given with each 250m pixel in the 9 beams (center beams are less noisy)
- Select 250m pixels in **space** and/or **time** domains
- Multiple strategies to select pixels of the 9 beams to remove outliers, deal with inter-beam bias ...
- Possible trade-offs: massive inversion or select only the most useful pixels ? Clean up of the outliers in the individual beams ?

$$h = \sum_{i=0}^{N-1} \sum_{j=1}^{B-1} w_{ij} h_{ij}$$

with $w_{ij} = 1 / \sigma_{h_{ij}}^2$ $\sum_{j=1}^{B-1} \sigma_{h_{ij}}^2$

→ Best option to be selected by ADT and Science Team

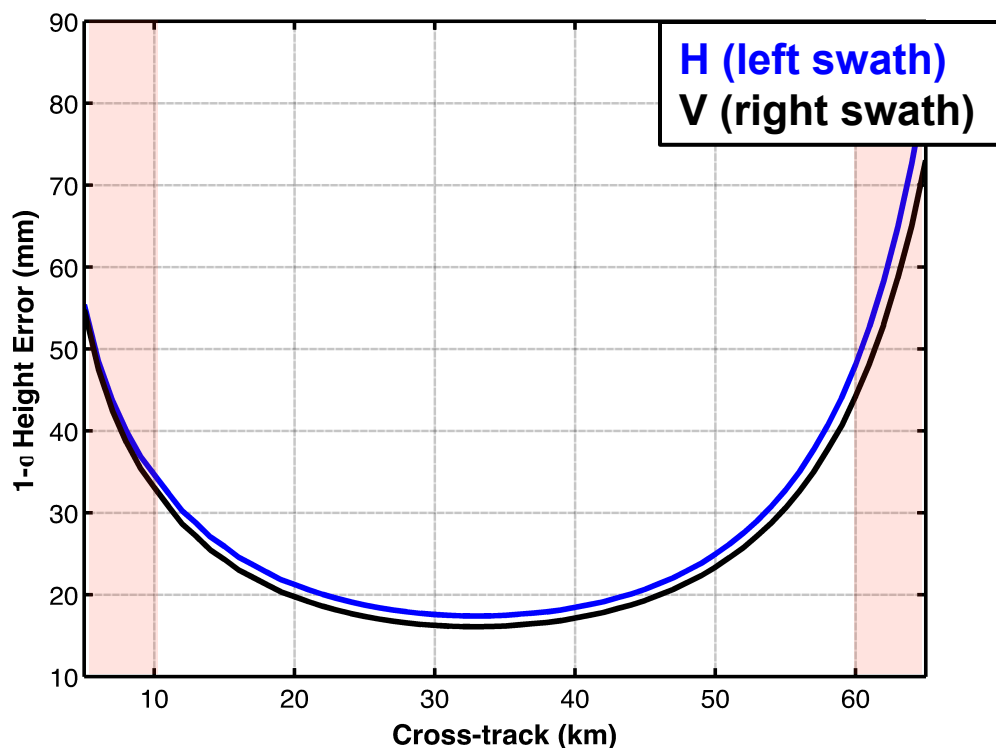




1 km² product noise

After beam combination over the product grid, the height random error is required to be less than 2.4 cm over 1 km², averaged over the swath, for SWH = 2 m

	Allocation	CBE (H/V)	-2.9dB SNR
Average (10-60 km)	2.4 cm	1.71/1.63 cm	2.4 cm



Beam combination

- On the product grid
- 2 Level-2 1-km² products (swath & fixed)
 - 2 beam combinations to be performed (TBC)
 - To avoid additional interpolation



PRODUCT DESCRIPTION



L2 product: content

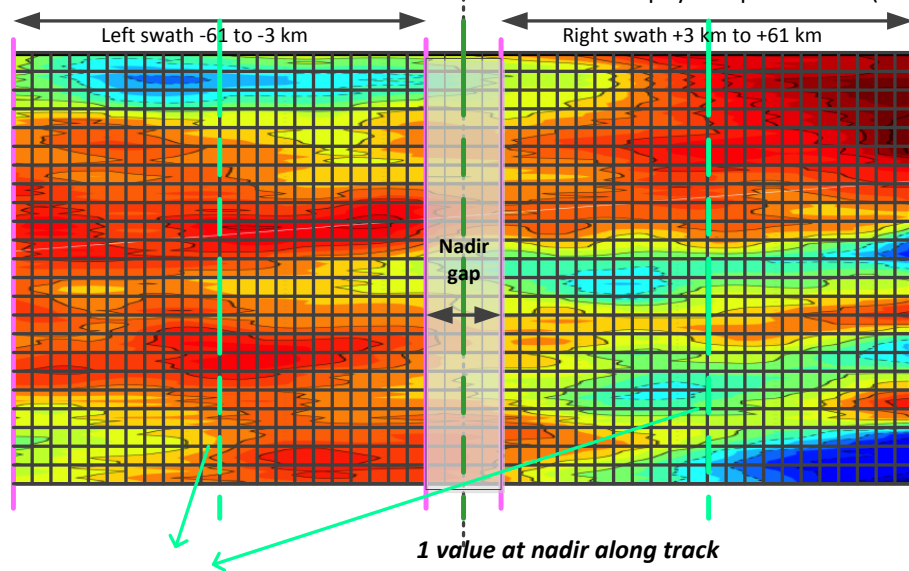
- Image of SSH, SWH, σ_0 , associated corrections and various flags

2D data provided in swath

Latitude, Longitude
Surface type
SSH, σ_0 , SWH
Associated uncertainties, quality indicators
Ice and rain flags
Corrections (geophysical and calibration)
Geophysical parameters (MSS, tides, ...)

2D data provided in swath

Latitude, Longitude
Surface type
SSH, σ_0 , SWH
Associated uncertainties, quality indicators
Ice and rain flags
Corrections (geophysical and calibration)
Geophysical parameters (MSS, tides, ...)



1 value per swath

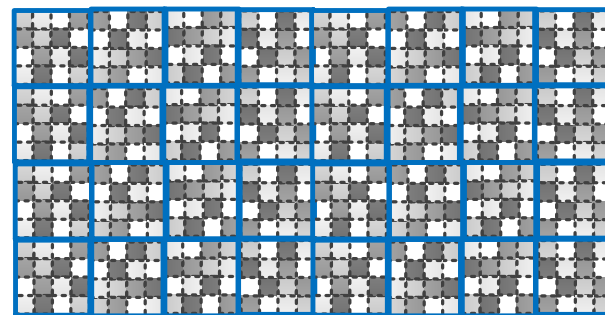
Radiometer BT measurement in their geometry (at TBD° in the swath)
Other radiometer parameters

1 value at nadir along track

Time tag
Orbit data
Nadir altimeter measurement (Jason like product in a separate file)
TBD: some of the geophysical corrections or parameter and an associated algorithm to propagate across the swath

High resolution σ_0 at 250 m x 250 m are provided in the product

From KaRIn central beam amplitude



☐ σ_0 image at 250 m x 250 m

☐ SSH product at 1 km x 1 km



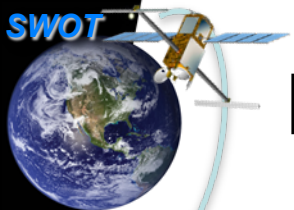
L2 - CONTENT SUMMARY

	L2A_LR_1km (< 15 GB/day)	L2B_LR_1km (< 5 GB/day)	L2A_LR_250m_9B (< 300 GB/day) – not decided
Data	Resolution and posting	Resolution and posting	Resolution and posting
Navigation, sat height, orbit flags	X one value at nadir	X one value at nadir	X one value at nadir
latitude/longitude for each pixel	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	X 9 beams, 500m x 500m pixels, 250m posting
Surface type	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	X 9 beams, 500m x 500m pixels, 250m posting
Distance to coast	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	
Corrected SSH	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	X 9 beams, 500m x 500m pixels, 250m posting
Corrected SWH	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	
Corrected Sigma0	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	X 9 beams, 500m x 500m pixels, 250m posting
Wind speed	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	
SSH slopes	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	
Quality information	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	
KaRIn 250m sigma0 measurements and variance	X 250mx250m, 250 m posting		
KaRIn range, SWH, sigma0 uncertainties	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	
KaRIn specific parameters	X 1km x 1km pixels, 1 km posting		
KaRIn coherence and various uncertainties			X 9 beams, 500m x 500m pixels, 250m posting
KaRIn instrument and Cross-over corrections	X 1km x 1km pixels, 1 km posting		
Ocean media corrections	X 1km x 1km pixels, 1 km posting		
Nadir altimeter product	X Nadir altimeter resolution and posting	X Nadir altimeter resolution and posting	
Wave, wind, sigma0 corrections or references	X 1km x 1km pixels, 1 km posting		
Radiometer data product	X Radiometer resolution, 1 km posting	X Radiometer resolution, 1 km posting	
MSS	X 1km x 1km pixels, 1 km posting	X 1km x 1km pixels, 1 km posting	X 9 beams, 500m x 500m pixels, 250m posting
Geophysical references	X 1km x 1km pixels, 1 km posting		
Geophysical corrections (tides ...)	X 1km x 1km pixels, 1 km posting		

Heritage from Jason products
(Geophysical Data Record)
+ Specific to interferometry

Reduced set of
parameters
(convenience)

Minimal set of
parameters (9-beam
data volume)

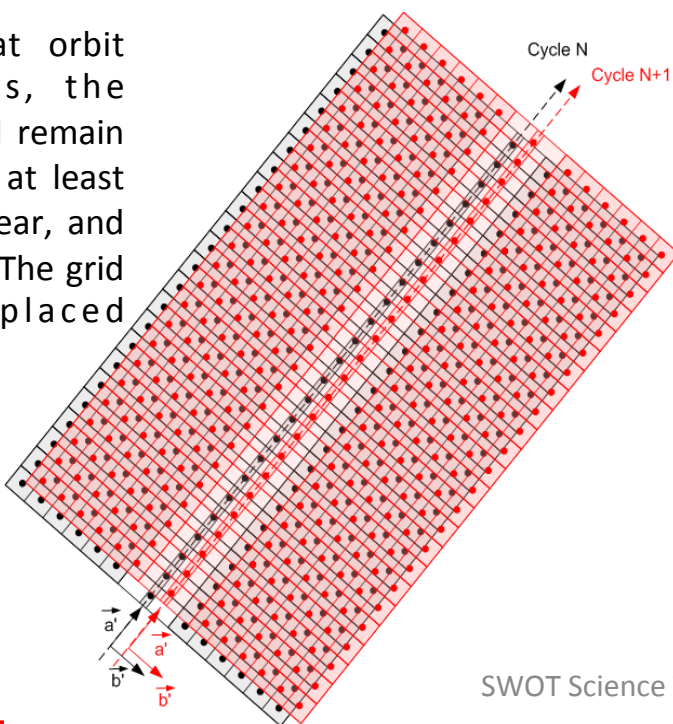


Level-2 LR product: grid baseline

□ L2A_LR_1km : on a “native grid”, i.e. swath-oriented nadir-centered grid

- $(1 \text{ km})^2$ pixel, 1 km posting
- Grid is centered on sub-satellite point and oriented with instrument angles (along and across-track).
- Native grid makes it possible to preserve higher resolution and directionality content (avoid spatial smoothing for $\lambda \sim 1\text{-}3 \text{ km}$)

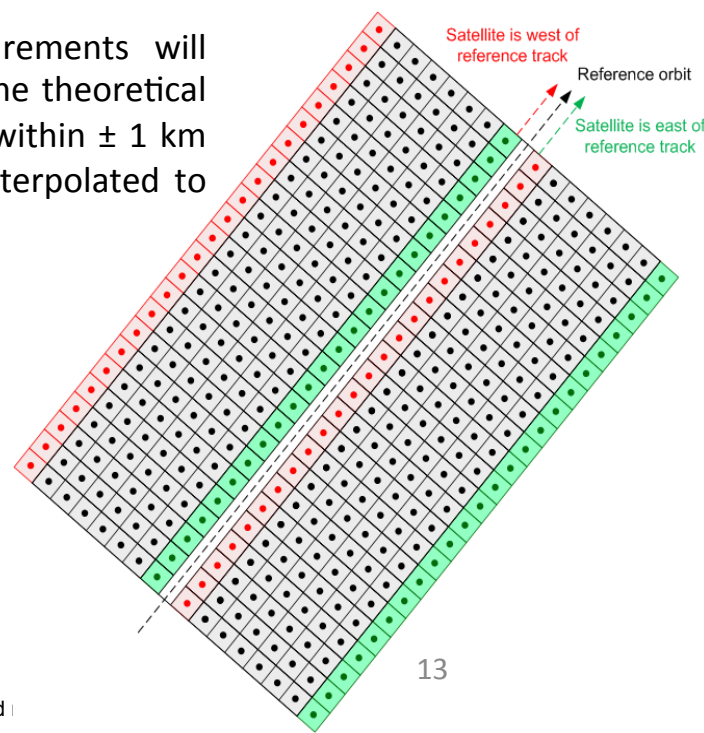
Due to repeat orbit requirements, the nadir track will remain within $\pm 1 \text{ km}$ at least 90% of each year, and $\pm 2.5 \text{ km}$ max. The grid will be displaced accordingly.

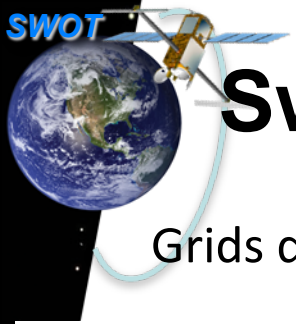


□ L2B_LR_1km : on a swath oriented geographically fixed grid

- Defined from the nominal orbit tracks. Grid is oriented along instrument directions (along/across track). Pixel location is geographically fixed for all revisits
- Spare pixels used to account for orbit variability (use extra pixels in red or green depending on where the nadir track is)
- Slightly more convenient for time series

Actual measurements will vary around the theoretical ground track within $\pm 1 \text{ km}$ and will be interpolated to this fixed grid

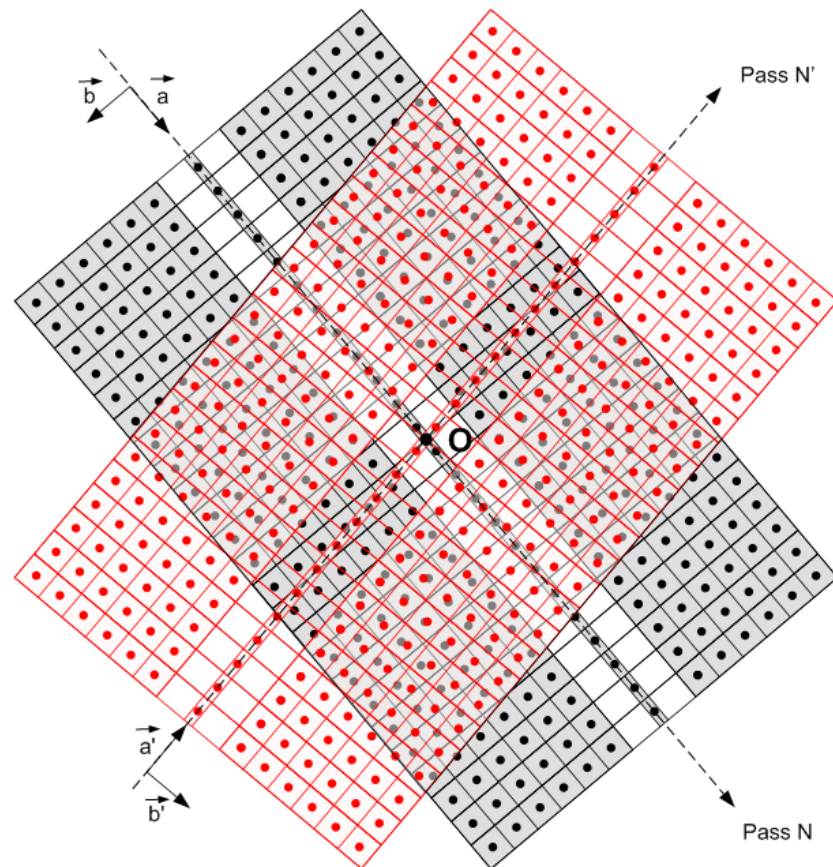
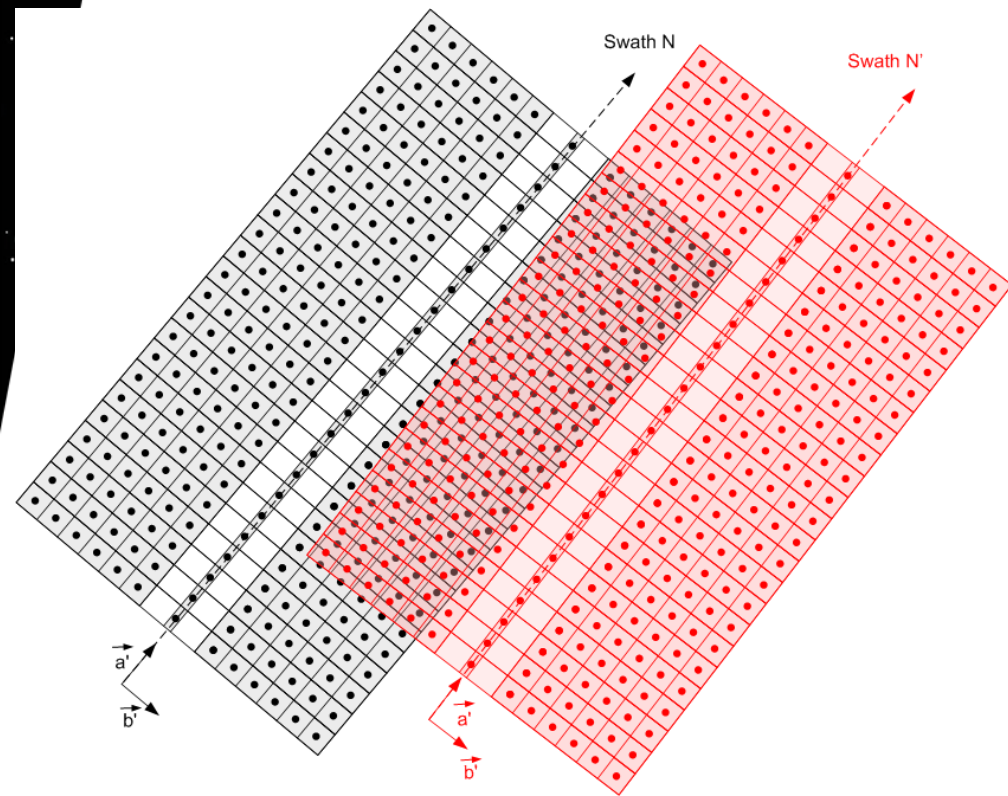




Swath oriented geographically fixed grid

Grids do not align for overlapping swaths

Grids do not align for crossovers



⇒ Additional reinterpolation needed to build complex time series when more than 2 swaths are considered



Level-2 LR expert product

- L2A_LR_9B

- Complement to the L2A_LR for experts, has been addressed during last SDT/ADT
- The intermediate 9-beam, 250 m posting, geolocated and corrected SSH information is calculated as an intermediate step, but not as a stored and/or distributed product (significant impact on daily data volume)
- ~ 290.4 GB / day

- Interest in such a product: refer to Rosemary Morrow summary

- Outlier detection: moving structures (sea-ice, icebergs, ships, ...) or permanent structures (islands, continental ice, oil platforms, coral reefs ...) will increase the height error
- Sea-ice, iceberg and continental land-ice applications: extra information in SSH from different look angles, and having the capacity to "tune" the beam combinations over the different surfaces (eg ice sheets), would be very useful
- Terrestrial surface water applications: Having the full 9-beam information would allow combination of the information from each beam in a way that is optimally tailored to avoid land contamination
- Wave detection (residual wave bias signatures)
- Marine geodesy applications



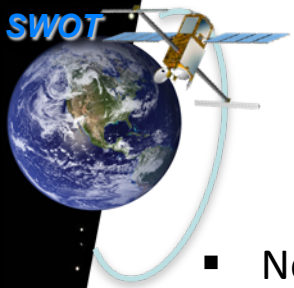
LR data volume budget

Product	Data volume / day (includes 30% margin)	Data volume / half orbit
L2A_LR_1km	15,5 GB / day	~ 570 MB / half orbit
L2B_LR_1km	5,1 GB / day	~ 181 MB / half orbit
L2A_LR_250M_9B	290.4 GB / day	~ 10.4 GB / half orbit



Possible file decomposition and volumes (L2A)

File	Content summary	Volume / half orbit	Volume / day
File 1	Corrected SSH , with locations and surface type, rain/ice flags, navigation, MSS and SSH Quality flag	0,08 GB/half orbit	2,86 GB/day
File 2	wind/wave file	0,046 GB/half orbit	1,66 GB/day
File 3	sigma0 at 1 km with location	0,037 GB/half orbit	1,35 GB/day
File 4	geophysical corrections and references, with quality flags	0,122 GB/half orbit	4,45 GB/day
File 5	sigma0 images and variance at 250 m	0,139 GB/half orbit	5,05 GB/day
File 6	Nadir altimeter product (GDR)	0,006 GB/half orbit	0,172 GB/day



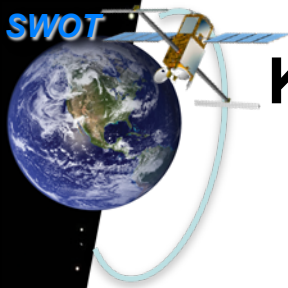
Open points, remaining work

- Need ST recommendation on the value of a 9-beam SSH expert product
- Some robustness / additional algorithms are proposed as a baseline as an output of the OBP
 - High resolution power and variance will be kept in the LR product, and used in the LR data processing
 - ADT is working on how to use the additional outputs (Doppler centroid image for each swath and high resolution cross-track interferogram) in the most efficient way. Depending on the ADT outputs, either OBP outputs or ground processing outputs deduced from them might be added in the product
- Earth-fixed grid definition
- LR is a global product: what does not work for non-ocean surfaces?
 - Estuaries and coastal areas
 - How to manage areas with both HR and LR data? Ocean/ice HR patches?
- A representative 1 pass sample of L2A product will be released in the coming weeks



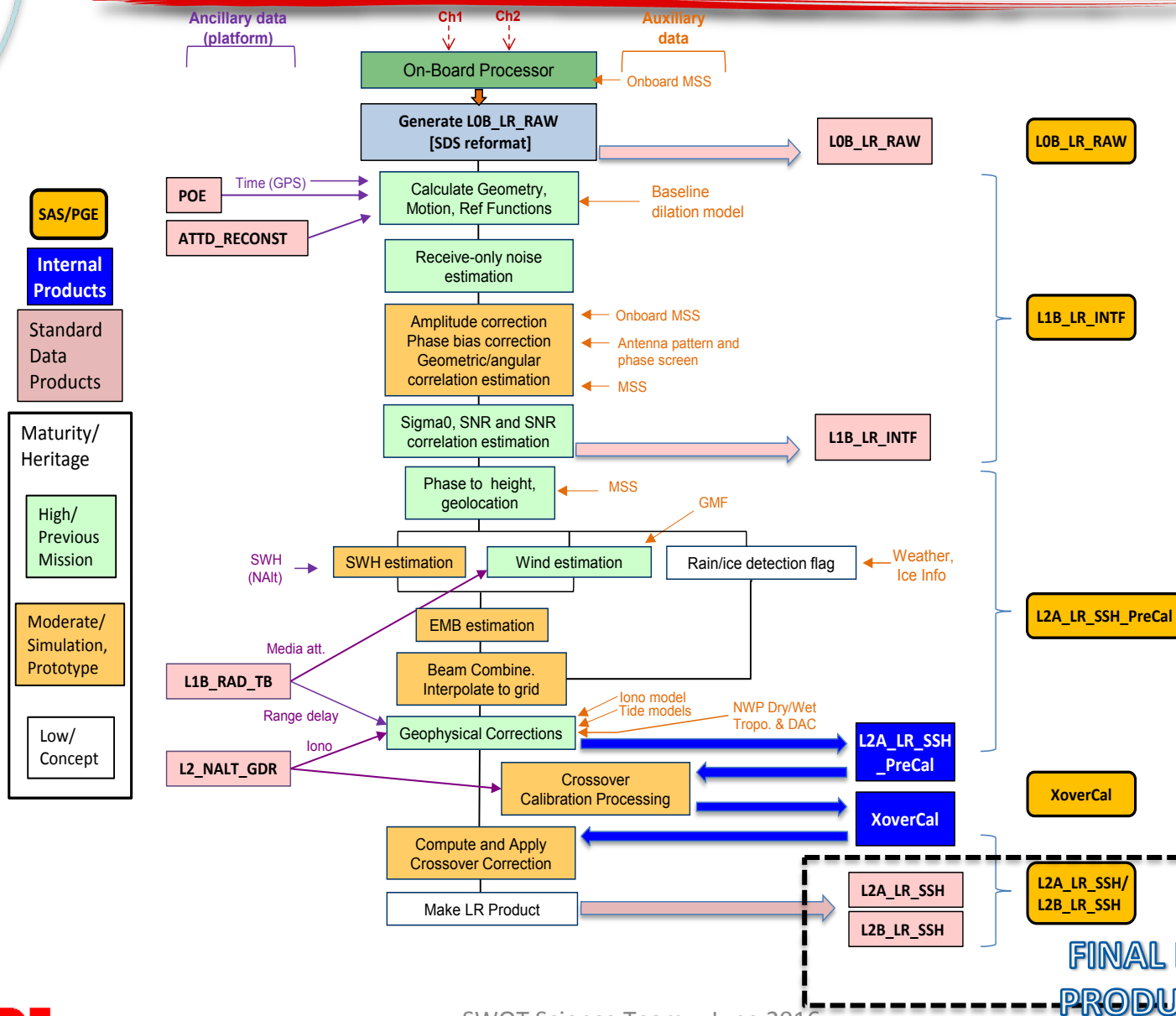
THANK YOU FOR YOUR ATTENTION

Back up slides



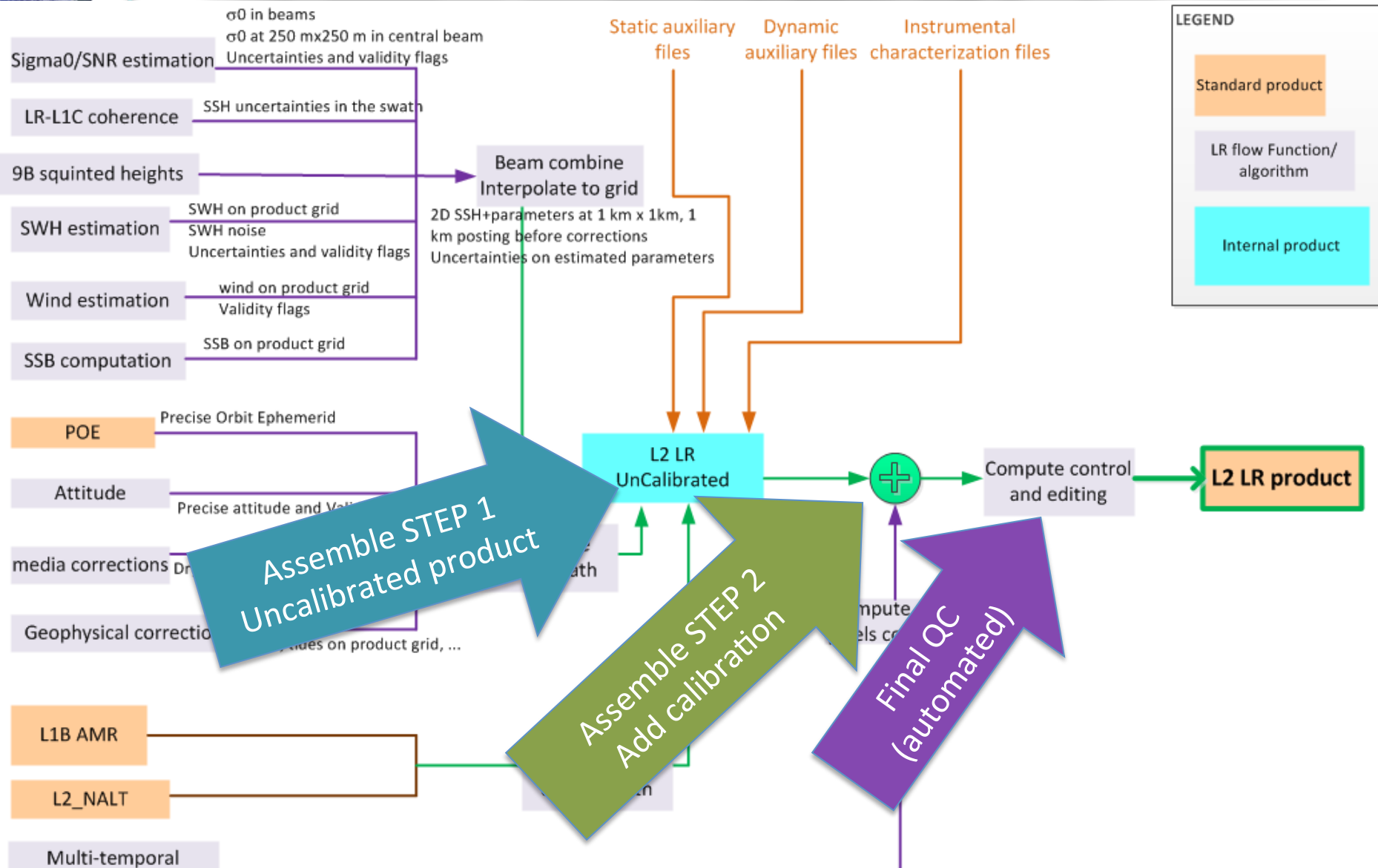
KaRIn LR/Ocean Processing Functional Flow

(most recent version, included in ADD draft)





Assembling the final product



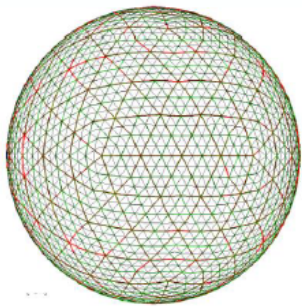


Global Earth-fixed grid

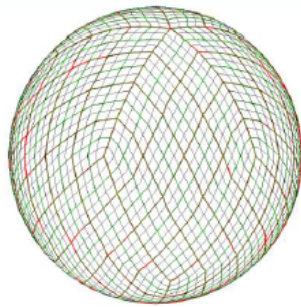
- Global fixed-resolution grid: the sphere is divided into a regular grid of ~ 1 km cells
 - Choosing the grid: trade-off between grid regularity and simplicity
 - And how do we process other KaRIn outputs?
- ⇒ Expected recommendations from the science team

Discrete Global Grid Systems (DGGS) from
Open Geospatial Consortium (includes NASA and CNES)

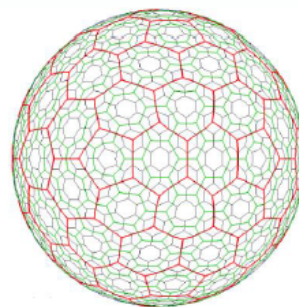
- Truly regular grid: distance between pixels on a sphere is constant
- Sphere is divided into polygon patterns
- Pixels are located with mesh indexes (not a simple 2D grid)



triangle



quadrilateral

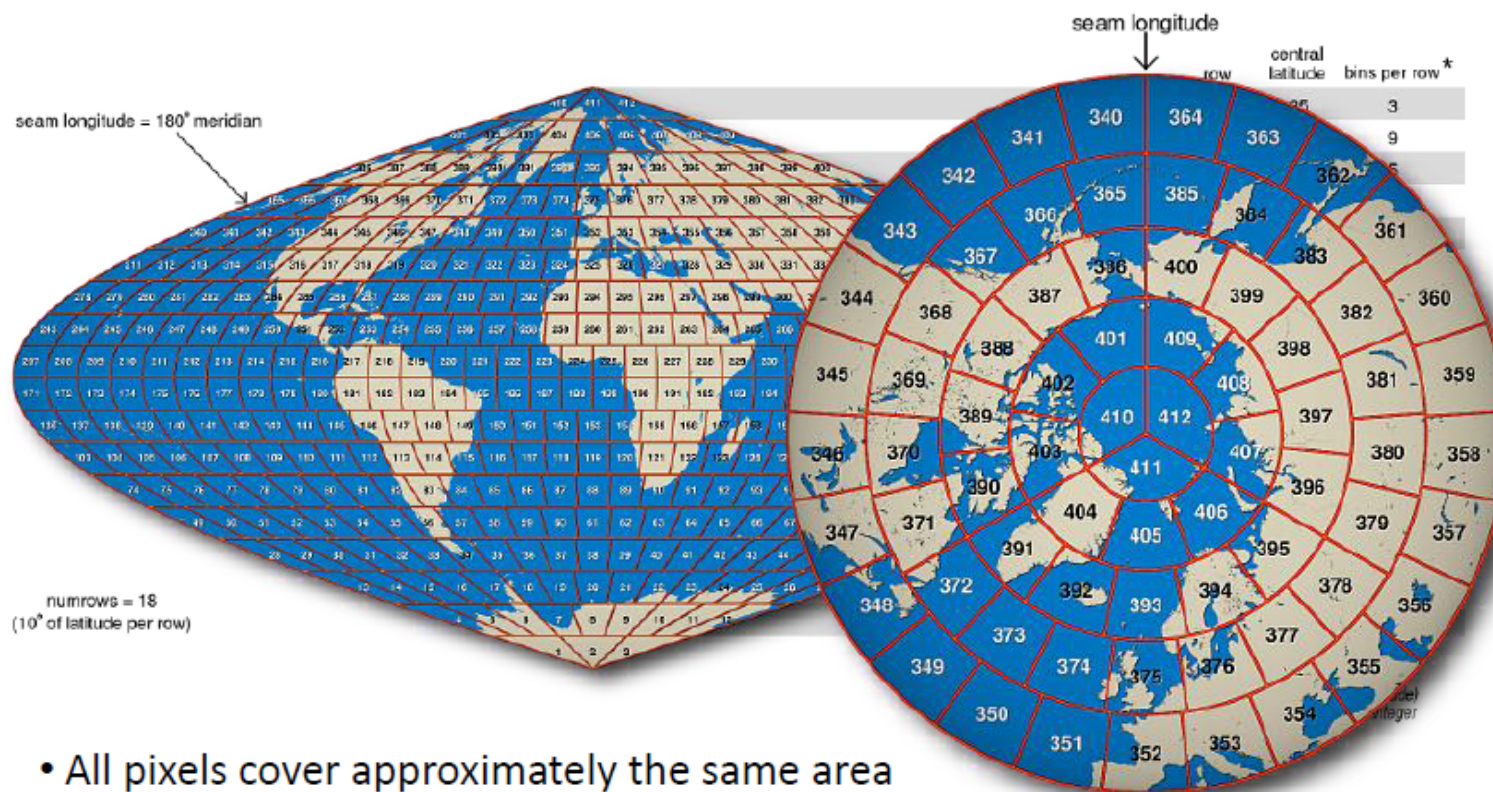


hexagon



Earth-fixed: example 2

Level-3 Ocean Colour from NASA/GSFC (sinusoidal map)

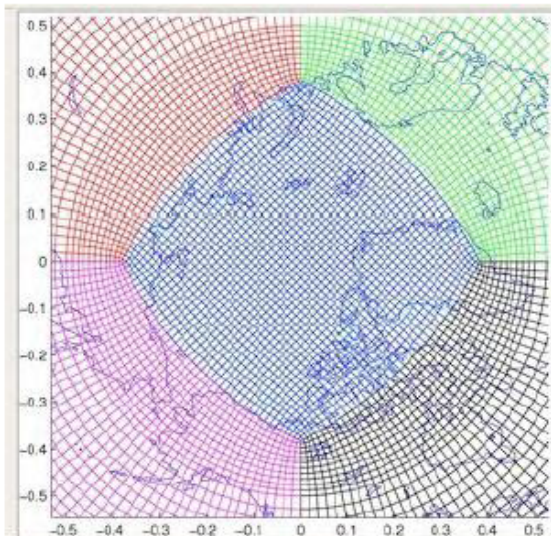


- All pixels cover approximately the same area
- Fewer pixels at higher latitudes



Earth-fixed: example 3

MITgcm: LLPC for Lat/Lon/Polar/Cap



Topologically equivalent to a cubed-sphere (here 1°)

Example shown:

- Telescopic from 0.25° to 0.8° (25°N/S)
- Isotropic to 81°S
- 90×90 polar cap North of $\sim 65^\circ\text{N}$

Resolution not constant

Tricky transition between 3 sub-grids



Level-2 LR product: definition

L2A

- Definition inherited from Jason GDR products: similar geophysical content, corrections, auxiliary data, as 2D images instead of along-track data...
- SWOT-specific fields : interferometry-related, uncertainties, Xover calibrations...
- Basic content:
 - Corrected topography and quality flags
 - All the corrections that have been applied and uncertainty estimates
 - Most useful references fields (e.g. geoid, mean sea surface).
 - Parameters given at 1km resolution only when it is relevant (keep volume in check)
 - Other KaRIn OBP products: σ_0 and σ_0 variance (250 m resolution & posting)
- 1 km² for low level of noise (2.4 cm for SWH = 2 m) and reasonable volume
- Subsets of ½ orbits (passes)
- L2A might be decomposed into subsets of parameters (by user typology)
 - In particular it would allow a "light" SSH file, containing corrected SSH with locations and surface type, rain/ice flags and navigation

– L2B

- Same content as L2A applied on a geographically-fixed grid
 - Contains fewer fields than L2A_LR_1km (more convenient for oceanographers)
- Level-2 Ocean data product overview has been issued and will be updated in the coming months